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Efficient modeling and forecasting of electricity spot prices

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A B S T R A C T

The increasing importance of renewable energy, especially solar and wind power, has led to new forces in the formation of electricity prices. Hence, this paper introduces an econometric model for the hourly time series of electricity prices of the European Power Exchange (EPEX) which incorporates specific features like renewable energy. The model consists of several sophisticated and established approaches and can be regarded as a periodic VAR-TARCH with wind power, solar power, and load as influences on the time series. It is able to map the distinct and well-known features of electricity prices in Germany. An efficient iteratively reweighted lasso approach is used for the estimation. Moreover, it is shown that several existing models are outperformed by the procedure developed in this paper.

1. Introduction

With the ongoing liberalization of electricity markets over the past decades, the volume of electricity traded via exchanges has greatly increased. This in turn led to an increasing transparency of the price for electricity. Due to the substantial dependence of companies and private households on this price, modeling electricity prices has become one of the cornerstones of research into the energy markets. But such modeling turns out to be at the edge of many disciplines in research. For instance, the analysis of the underlying trade mechanisms can be allocated to economics. But the energy production itself is a process which can be related to engineering and the rules governing the exchange of energy, especially renewable energy production, are determined by law and politics. Hence, modeling electricity prices can be a complex issue. This is also reflected in the time series, where many unusual but already stylized facts can be observed.

The model proposed in our paper tackles this complexity in several ways. Its distinctive features compared to the existing literature can be boiled down to seven key facts. Our approach: 1. Models the electricity price without any data manipulation, 2. Incorporates every established stylized fact of electricity prices, 3. Provides insights for the structure of the leverage effect, 4. Proves the effect of wind and solar power on price, 5. Accounts for specific holiday effects and daylight saving time effects in the wind and solar generation, 6. Does not need any future information to provide accurate forecasts. Finally, 7, it uses efficient and rapid state of the art estimation techniques.

We will fit our proposed model to the hourly electricity price of the European Power Exchange (EPEX) for the period of 28.09.2010 up to 01.05.2014. The data sets are obtained from the EPEX at www.epexspot.com for the hourly day-ahead spot price data of Germany/Austria, from the European Network of Transmission System Operators for Electricity at www.entsoe.eu for the hourly load data of Germany, and from the Transparency Platform of the European Energy Exchange (EEX) at www.transparency.eex.com for the hourly wind and solar power feed-in for Germany.[1]

Our paper is organized as follows. In Section 2 we give an overview about the setting in which electricity exchange takes place and name the distinct challenges occurring in modeling the time series. The

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[1] We remark that the load and renewable data for Austria is not included in the data as our main focus is the German energy market.

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subsequent section sets up our model, which aims to face those challenges. Section 4 presents the estimation procedures for our model. In Sections 5 and 6 we fit the model to the hourly electricity price time series of the European Power Exchange and apply a comprehensive forecast study. The last section concludes by discussing our findings.

2. Challenges in modeling electricity prices

Energy markets are a rapidly changing field of the economy. The liberalization of these markets and the subsequent development of the energy mix account for that fact. But as different countries worldwide face different preconditions, for instance politically or climatically, their energy markets tend to have a very heterogeneous structure. Hence, the findings for one country may not, or may only partly, be used for another country or region.

In the case of the German energy market, a substantial amount of the daily demand is traded via an exchange. Spot market trading takes place by continuous trading and auctions. Prices for this market can be obtained either from intraday trading or from day-ahead auction prices. The latter is represented by the EPEX spot auction price for Austria and Germany. EPEX is a member of the EEX group. Since 2008, the EEX has not prohibited negative prices (Keles et al., 2012). By considering all products of the exchange, there are currently 250 market participants at the EEX. Considering only the Austrian/German day-ahead auction of the EPEX results in 197 participating traders.

The non-negligible amount of market participants is also an aftermath of liberal energy laws in Germany, especially when renewable energy is considered. The Erneuerbare-Energien-Gesetz (EEG) and its corresponding enactments are governmental regulations which embody this idea of liberalization. As a consequence, the supply of energy from renewables rose significantly within the past years. Incentives, like feed-in-tariffs for renewables granted by the government, catalyzed this development. But the growing amount of power plants for renewables had a direct influence on the price for electricity, (Edenhofer et al., 2013), as such energy can be produced at a cost of almost zero (Würzburg et al., 2013).

Changes in the EEG in 2012 had direct impact on the marketing of renewable energy.[2] The EEG allows for marketing the produced renewable energy not only to TSOs or other market players but also directly at the exchange. According to §33g EEG, producers of such energy receive a market premium in addition to the market price for selling their electricity. Hence, also producers of renewable energy have an incentive to directly trade at the electricity exchange or to sell it via OTC business.

Nevertheless, other regulations have also affected the market directly. For instance, transmission system operators (TSO) are obliged to sell their electricity only on the day-ahead or intraday spot market, if they decide to use an exchange.[3] Hence, data since the publication of this regulation in 2009 are of special interest.

In the economic theory of competitive markets, the price of electricity should equal its marginal cost. As the feed-in of renewable energy with zero marginal cost replaces every other energy source with higher marginal cost, the price of electricity should decline (Keles et al., 2013). This is known as the merit-order effect. Furthermore, the demand curve for electricity can be assumed to be inelastic (Sensfuß et al., 2008) as a certain amount of power is needed regardless of the price. This implies that modeling the impact of renewables on the price of electricity is highly necessary, as those energy sources will always lead to a modified marginal cost structure as the share of renewable energy sources is increasing.

Empirical evidence for the reduction of electricity prices caused by the emergence of renewable energy has been shown by many authors

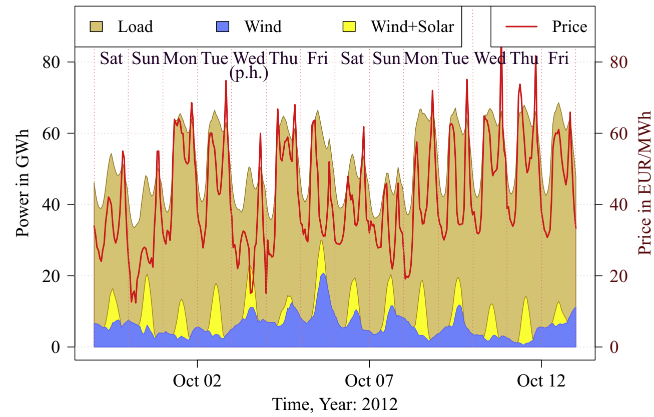

Fig. 1. The hourly load, wind and solar power feed-in with the corresponding spot price. The 3rd of October is a public holiday (German unity).

in the recent literature. For instance, Woo et al. (2011) use a regression analysis for the Texas electricity price market to examine the effect of wind power generation. Another multivariate regression approach was applied to German and Austrian electricity prices by Würzburg et al. (2013), where, among other time series, wind and solar power were examined and also led to a reduction in price. Huisman et al. (2013) obtained equivalent results for the Nord Pool market by modeling energy supply and demand.

This relation is also illustrated in Fig. 1, which shows the price, load, and the patterns of solar power and wind power for two weeks of October 2012. Whenever the combined effect of wind and solar power is high, the line representing the price seems to decline considerably.

But the introduction of renewables not only leads to a price reduction effect, it can also increase the goodness-of-fit for modeling the time series of prices. Concerning this, a comprehensive study was done by Cruz et al. (2011). They combined sophisticated models like Holt–Winters, ARIMA, and neural networks, with, e.g., wind power, and provided evidence for this inclusion's being beneficial to the price modeling. Also Yan and Chowdhury (2013), Liebl (2013) and Kristiansen (2012) obtained competitive goodness-of-fit statistics by including wind power in their approaches. Using a simulation study for the dependencies of the EEX electricity price and the wind power generation Keles et al. (2013) were able to show the advantages of including wind power.

The price of electricity is also heavily dependent on the day of the week and on the four seasons of the year (Weron, 2006). The reason for this is twofold. First, especially solar energy production depends on the period of sunshine: reduced, for instance, in winter. Second, the daily demand for electricity is dependent on the working days, e.g. whether industrial machines are running and require energy or not. An example of two observed months for illustrative purposes is given in Fig. 1. The light-brown shaded area represents the electric load pattern of the first two weeks of October in 2012. Comparing the price time series with the load time series indicates that both variables are positively related. As on weekends the load is usually lowered, weekends and weekdays[4] within the chosen period tend to exhibit different price patterns. This is also true for holidays, e.g. German unity day on the 3rd of October, where the price and the load are both lower than on other weekdays. A more detailed investigation of special days and phases of the day is done in Section 3.

The consideration of these effects is also an important topic in the literature. The weekly dependence is usually modeled in time series analysis by incorporating the equivalent lagged value, e.g. lag 168 for hourly data (e.g. in Kristiansen, 2012). Nevertheless, the consideration of

[2] Even more recent changes of the EEG and related laws in July and August 2014 are not considered within this article, as our dataset ends in May 2014.

[3] According to §2 AusglMechV.

[4] We use the term weekday to refer to the days from Monday to Friday.